

The background of the slide is a composite image. The left side shows a calm view of Yosemite Falls cascading down a rocky cliff into a pool of water, with green trees in the foreground. The right side shows a turbulent, high-velocity flow of water crashing over a structure, likely the Lower Yosemite Falls Footbridge, with a dark vertical post in the foreground.

CALIFORNIA FLOOD RISKS IN A CHANGING CLIMATE

*Michael Dettinger, US Geological Survey
Scripps Inst Oceanography, La Jolla, CA*

Yosemite Falls 5/16/07

Lower Yosemite Falls Footbridge 1/2/97

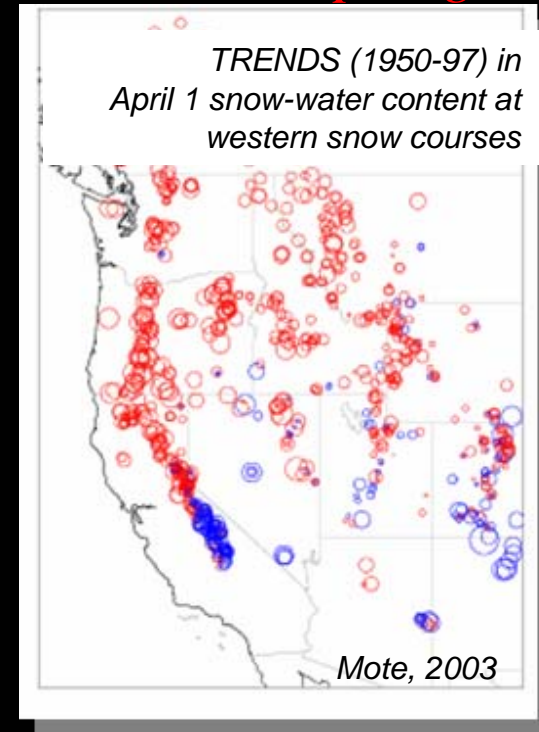
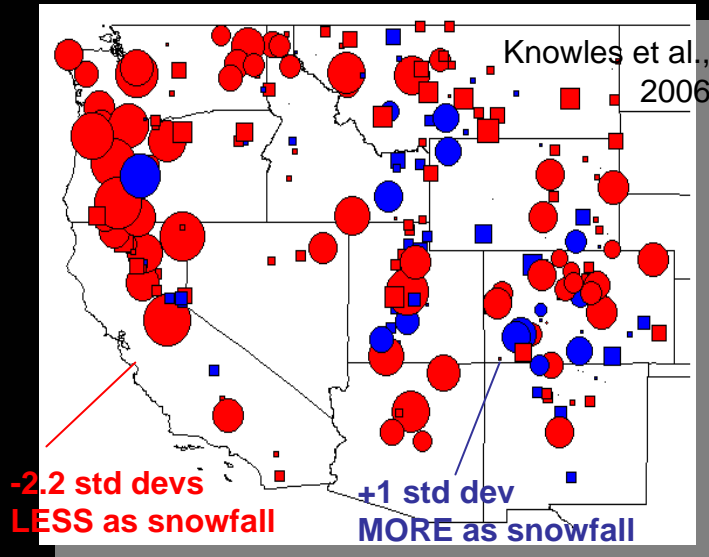


SCRIPPS INSTITUTE OF
OCEANOGRAPHY

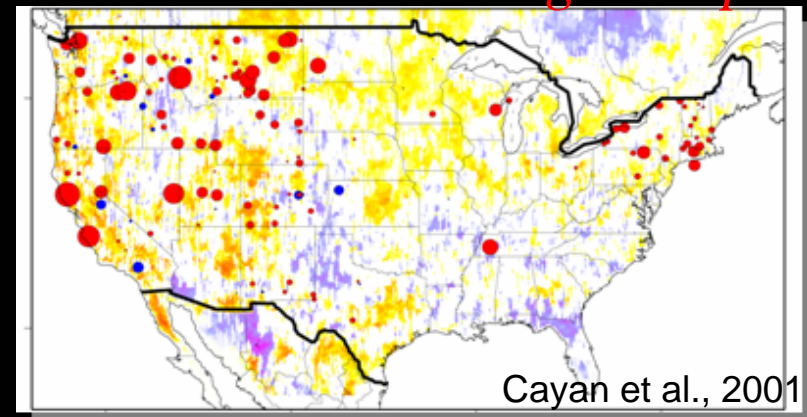
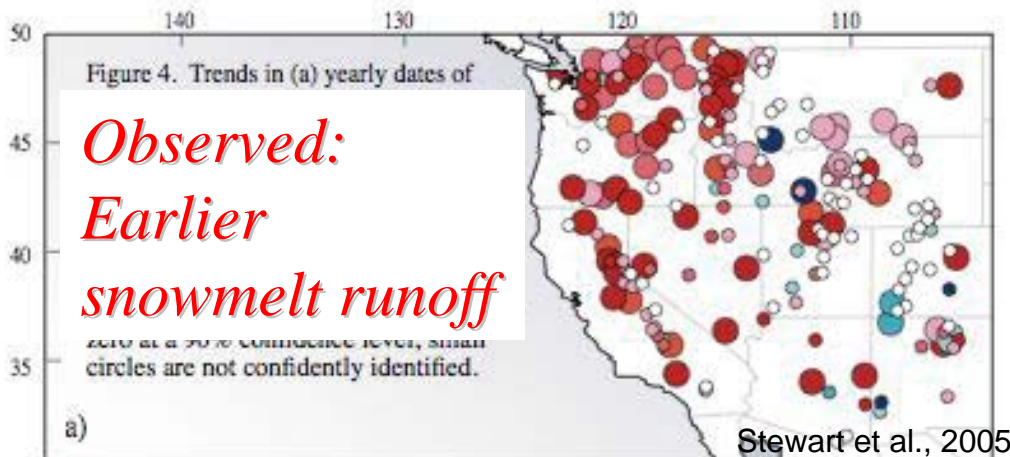
CEC's California Climate Change Center

Warming already has driven *Observed: Less spring snowpack* hydroclimatic trends.

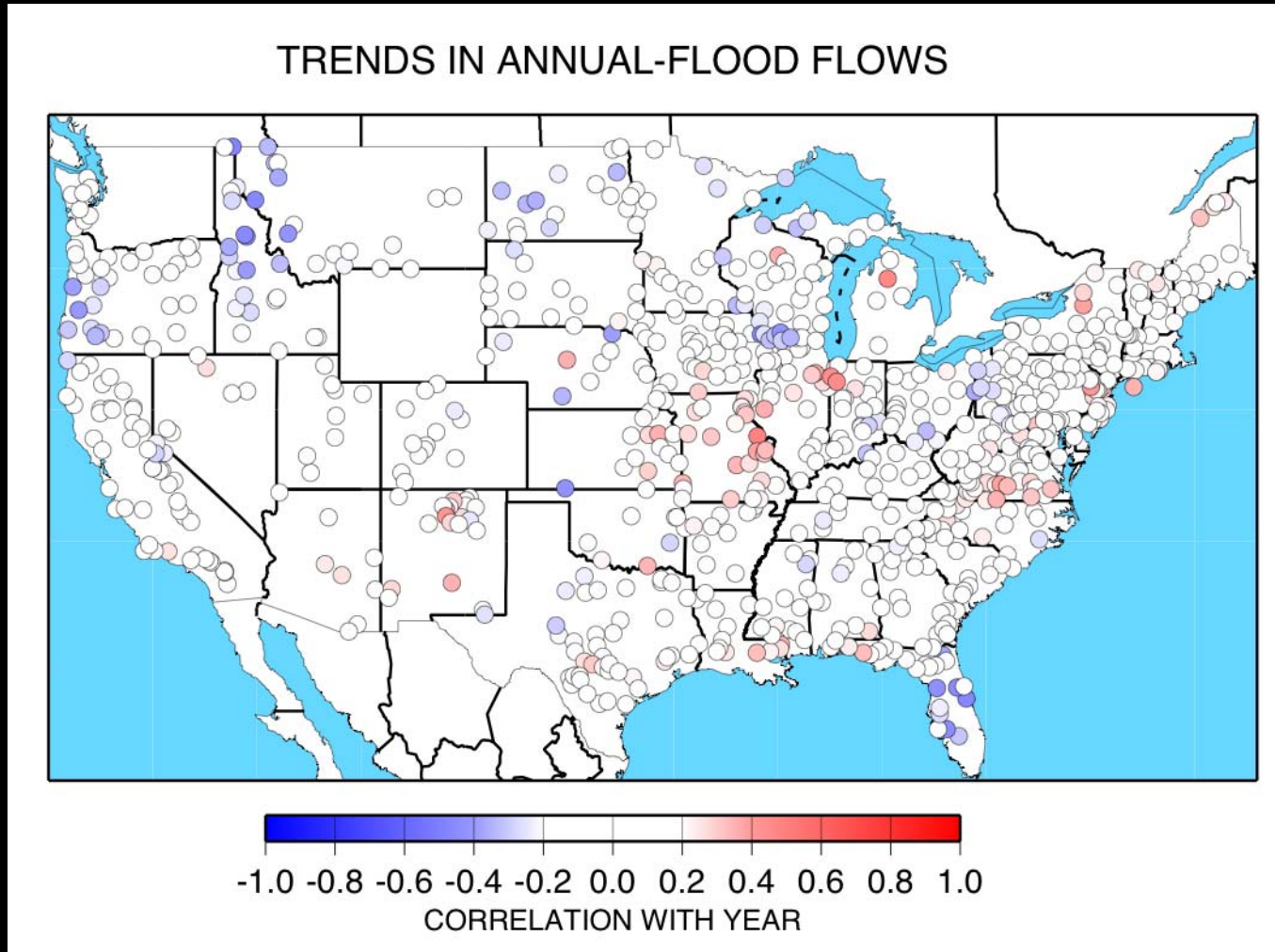
Observed: Less snow/more rain



Observed: Earlier greenup



However, NOT many trends in annual-flood series that meet even minimal tests of significance, 1947-2000.



So, should we be expecting increased flood risks, or not?

WHAT SHOULD WE EXPECT OF FUTURE FLOODS IN CALIFORNIA?

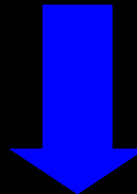
Rain or snow? Or just no snow?



Wet snows and soils? Or dry soils?



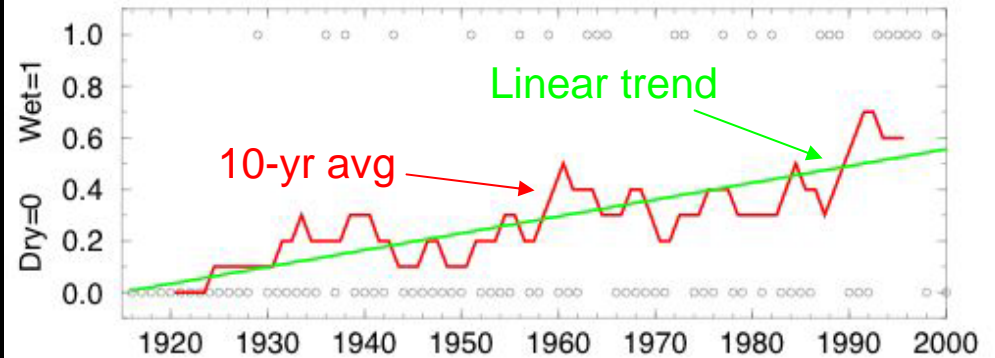
Larger storms? Or weaker storm tracks?



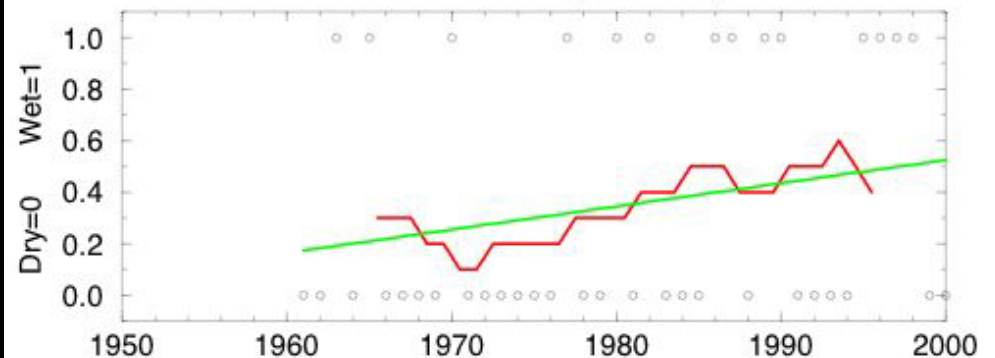
MORE OR LESS FLOODING?

Have annual-peak flows become more precipitation-driven (rain- or rain-on-snow fed) than heat-driven (snowmelt-fed) in recent decades?

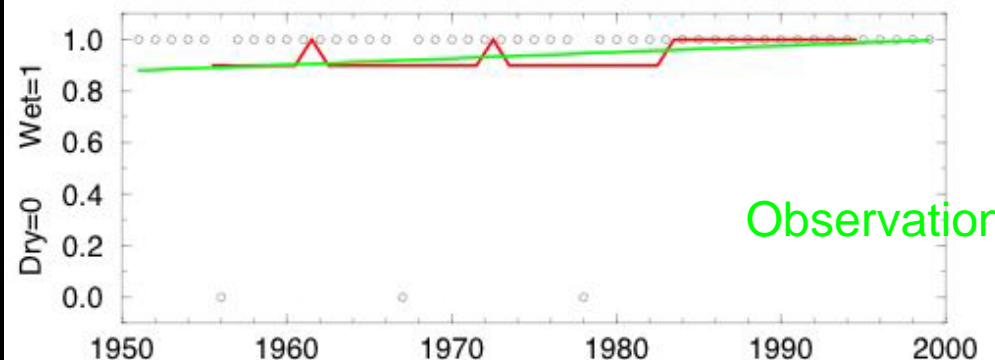
Did Annual Floods occur on Wet Days or Dry Days?
Merced (11264500)



East Fork Carson (10308200)

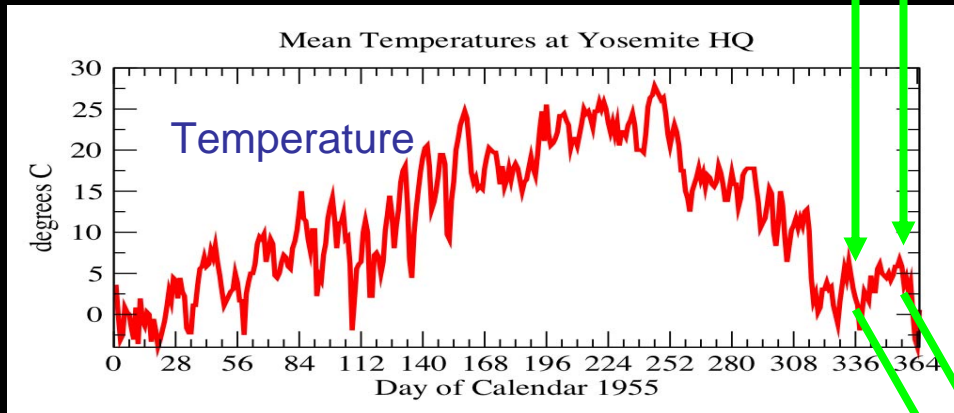
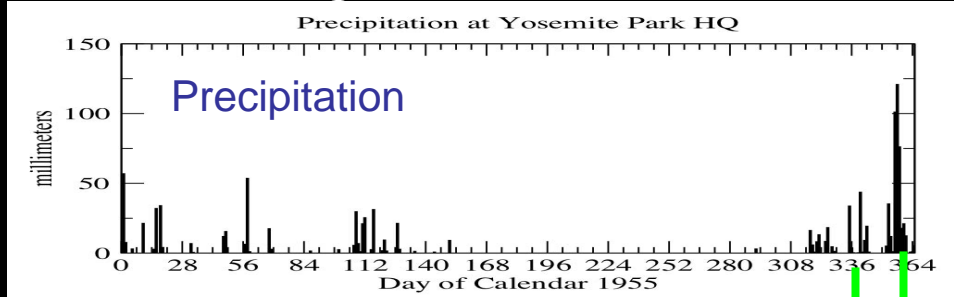


North Fork American (11427000)



If we assume a standard moist adiabatic lapse rate during all historical storms at Yosemite since 1916...

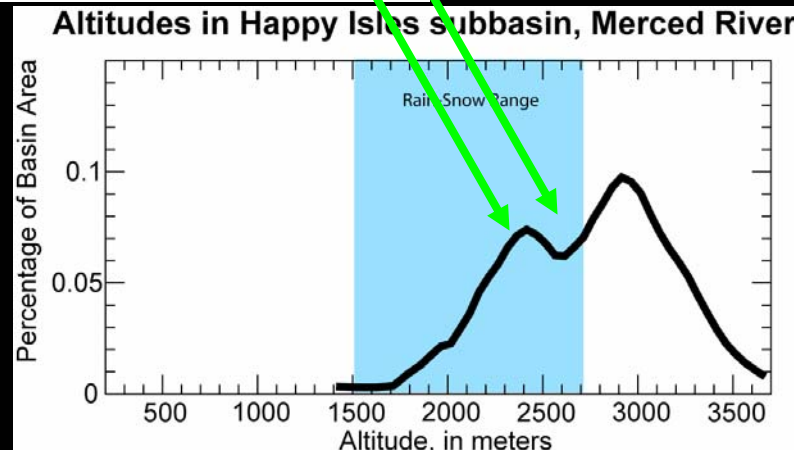
We can estimate the snowline for historical storms since 1916.



X -6.5C/km lapse rates

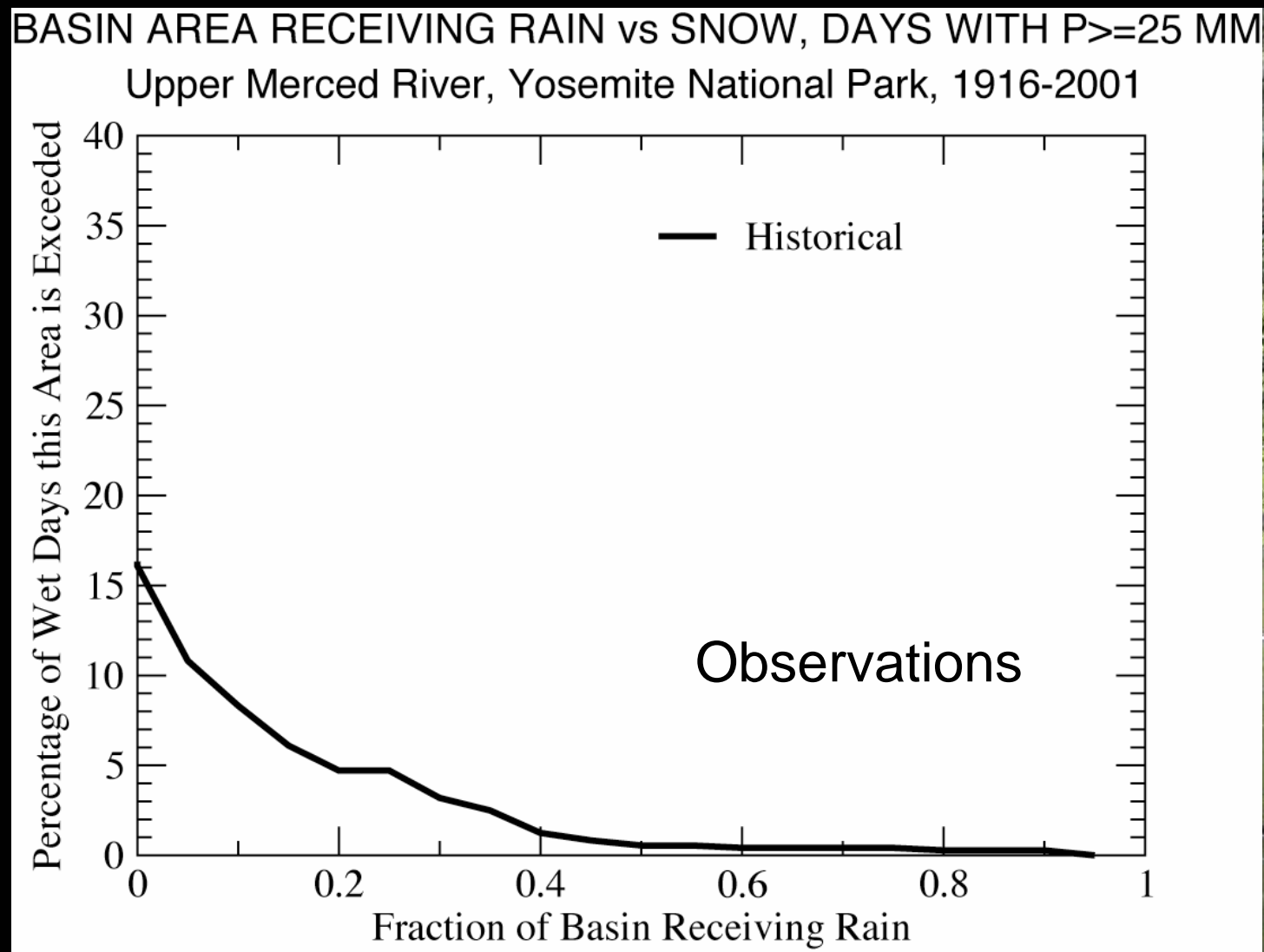
= freezing altitudes by storm

THEN, compare
Freezing
Altitudes to basin
hypsograph...



= rain-covered
Basin areas by
storm

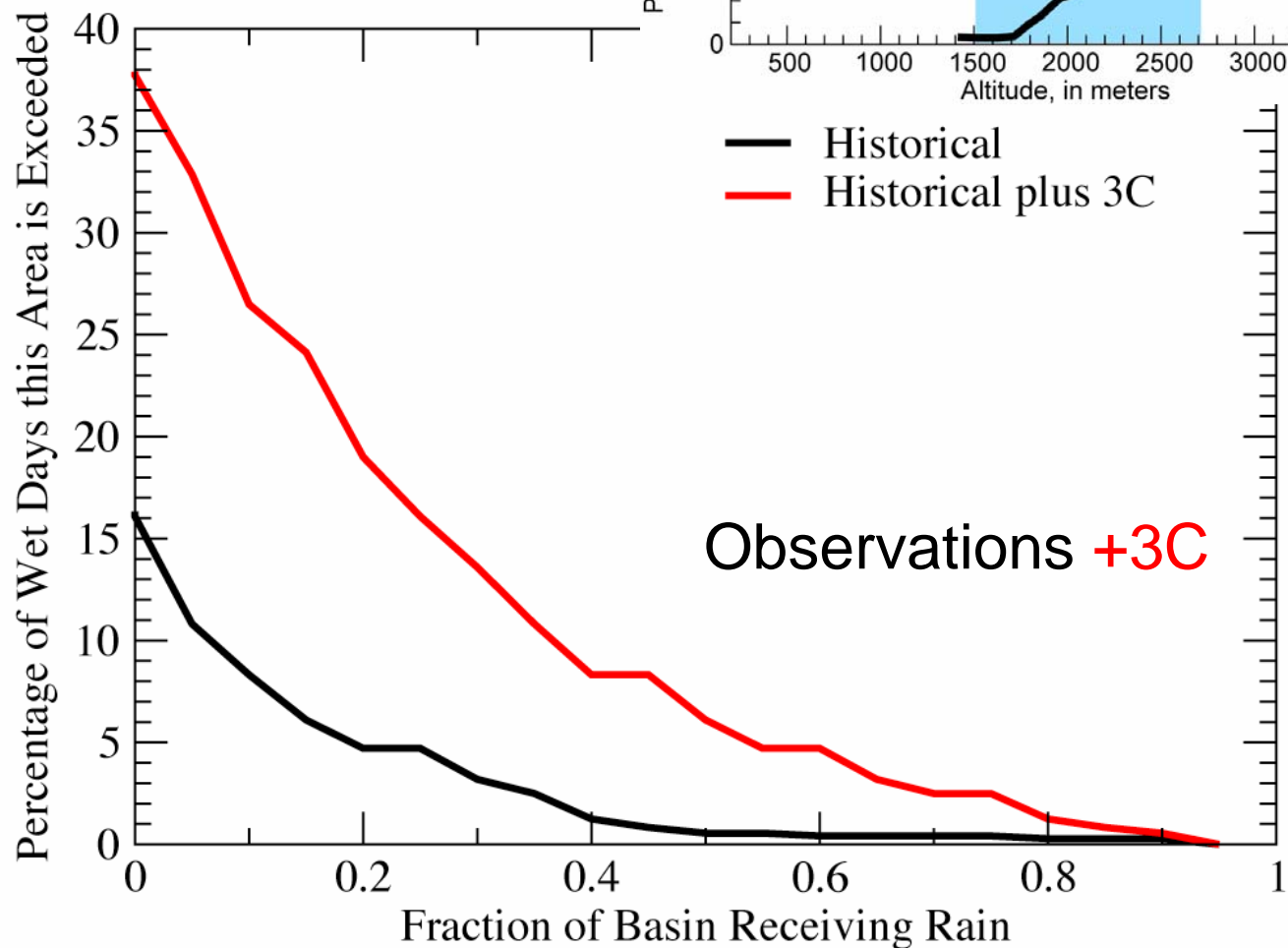
How much of the Merced R basin received rain (rather than snow) during 90 yr of historical storms?



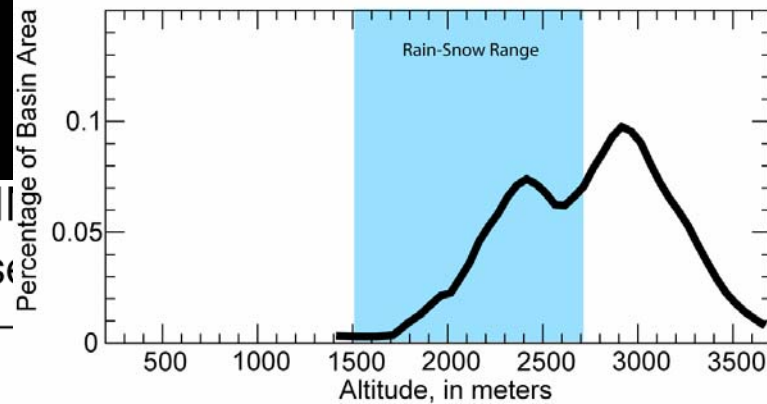
How much that would change if the climate warmed uniformly by $+3^{\circ}\text{C}$



BASIN AREA RECEIVING RAIN
Upper Merced River, Yosemite



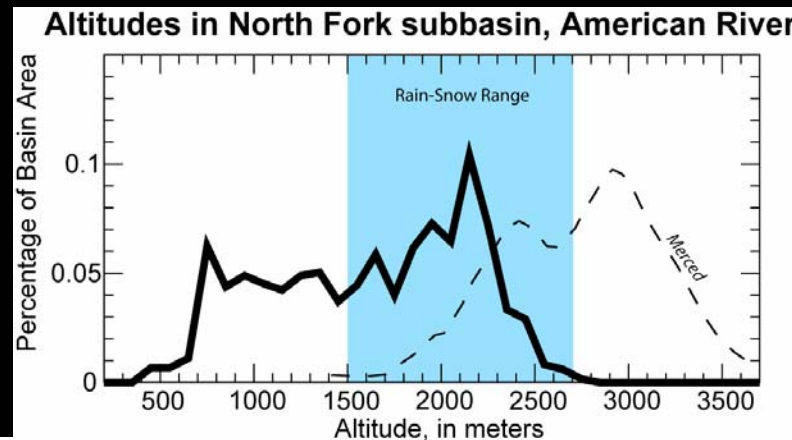
Altitudes in Happy Isles subbasin, Merced River



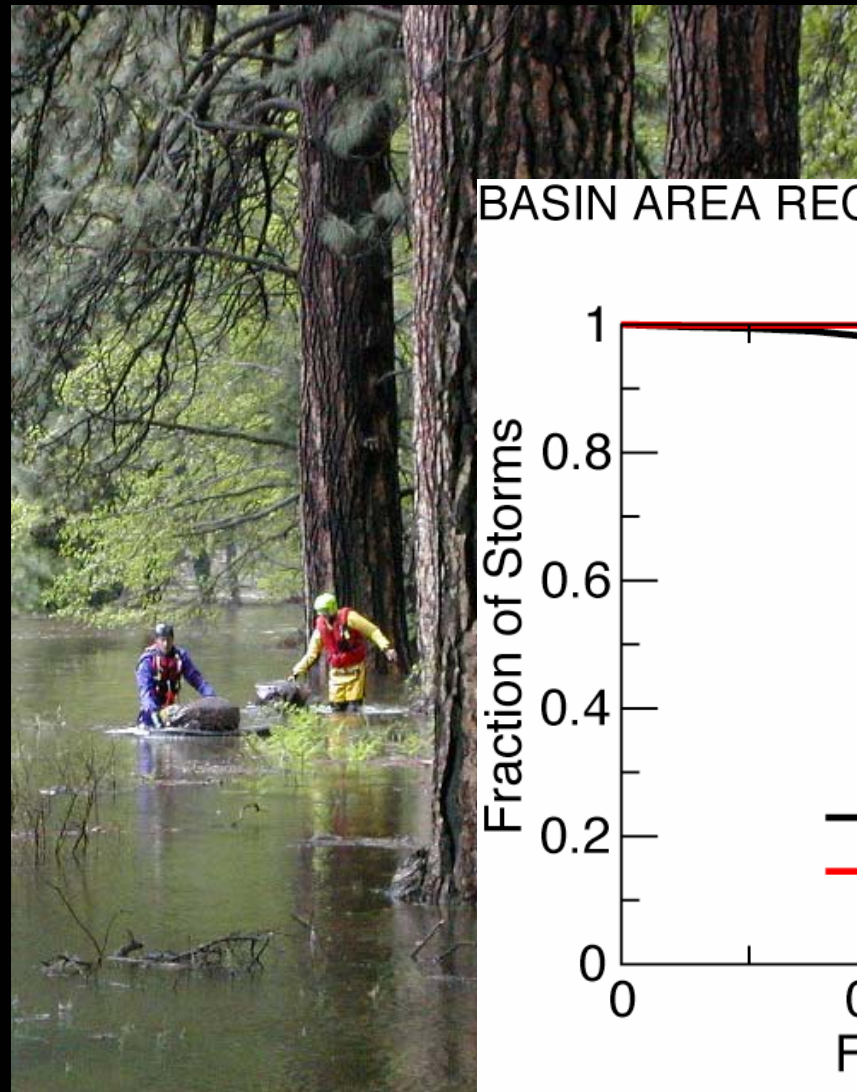
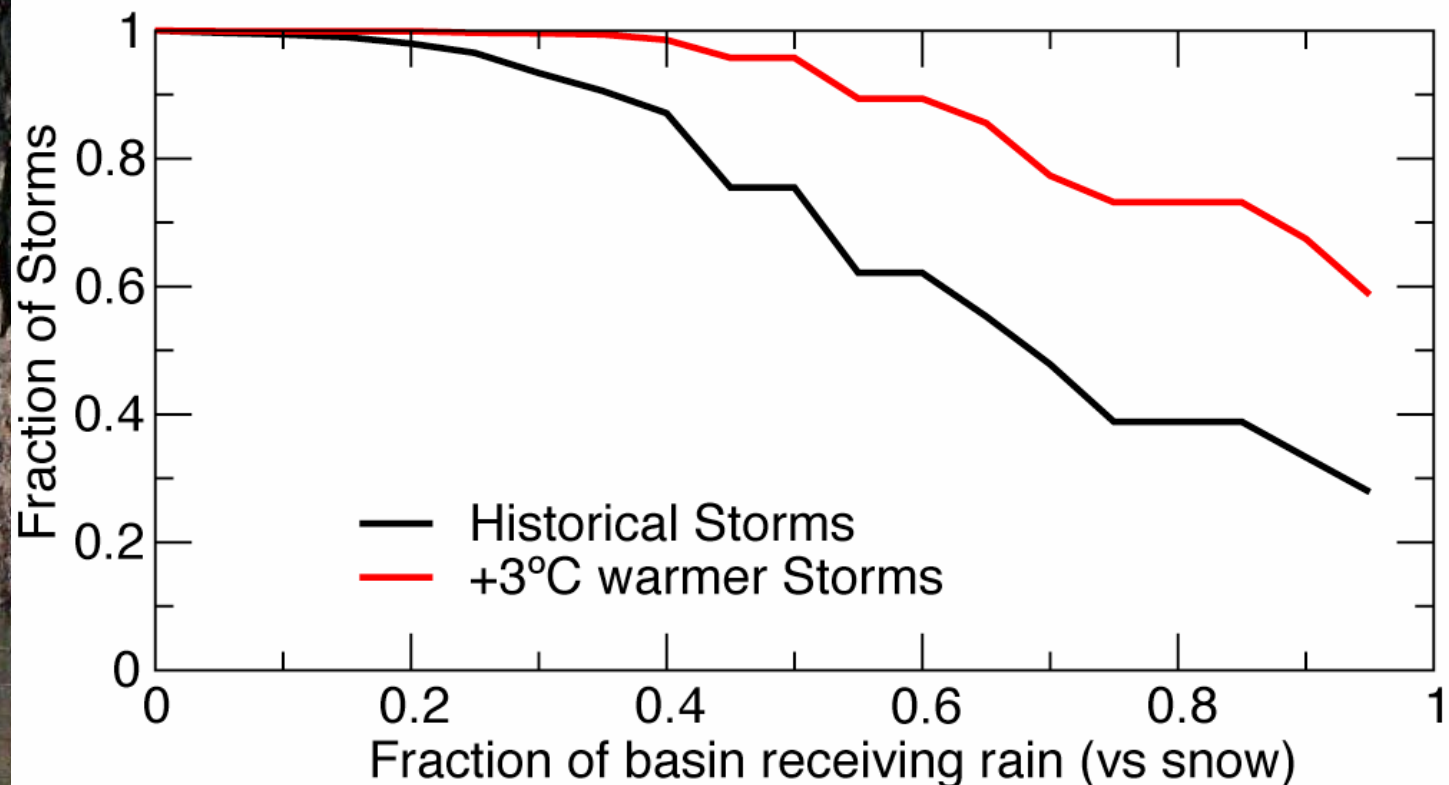
— Historical
— Historical plus 3C

Observations $+3\text{C}$

How much that would change with warming by $+3^{\circ}\text{C}$in another river



BASIN AREA RECEIVING RAIN vs SNOW, DAYS WITH $P \geq 25$ MM
North Fork American, 1949-99

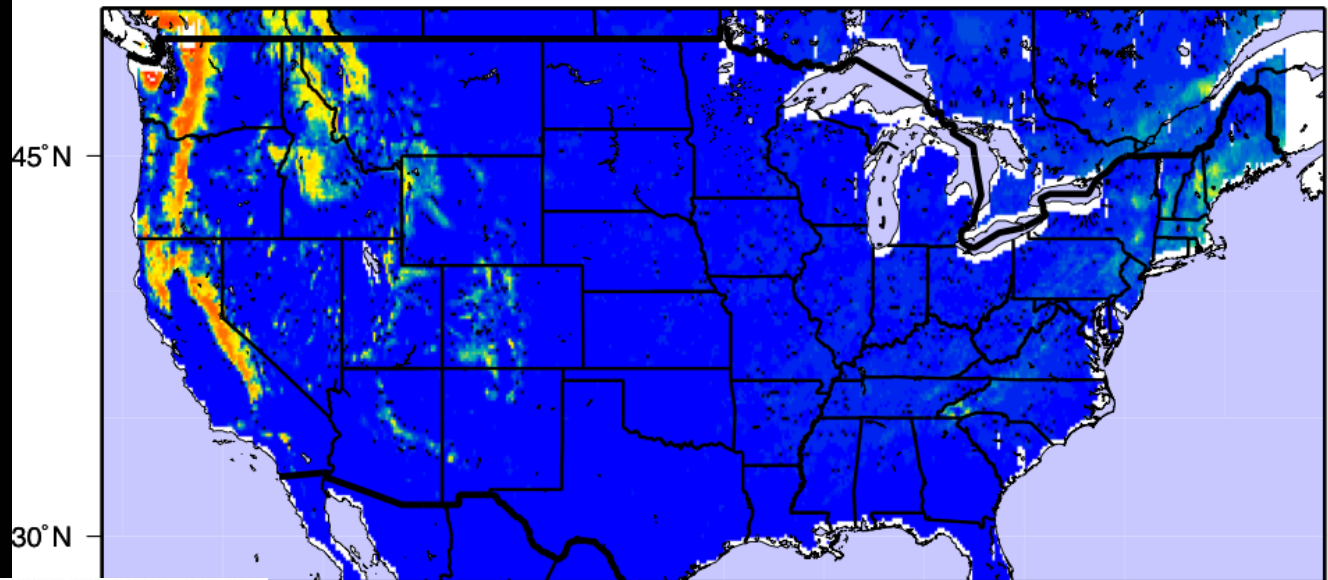


Using 1950-99 meteorologic OBSERVATIONS nationwide:

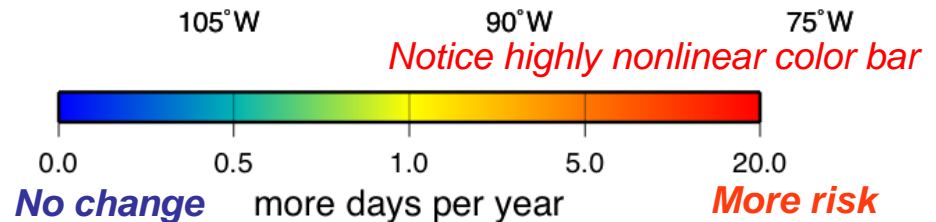
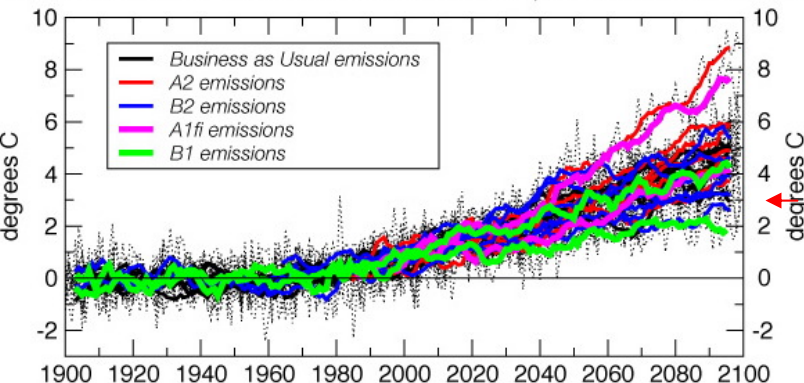
How widespread is this vulnerability?

Estimating influence of a uniform +3°C warming on frequency of rain-fed flood contributions

CHANGE IN NUMBERS OF WET DAYS ($p > 1$ INCH) ABOVE FREEZING WITH AN IMPOSED +3°C WARMING



PROJECTED CHANGES IN ANNUAL TEMPERATURE, NORTHERN CALIFORNIA



--> Sierra and Cascades are likely rainfed flooding hotspots!

Rain rather than snow ! --> Larger contributing areas



Wet or dry snows and soils?

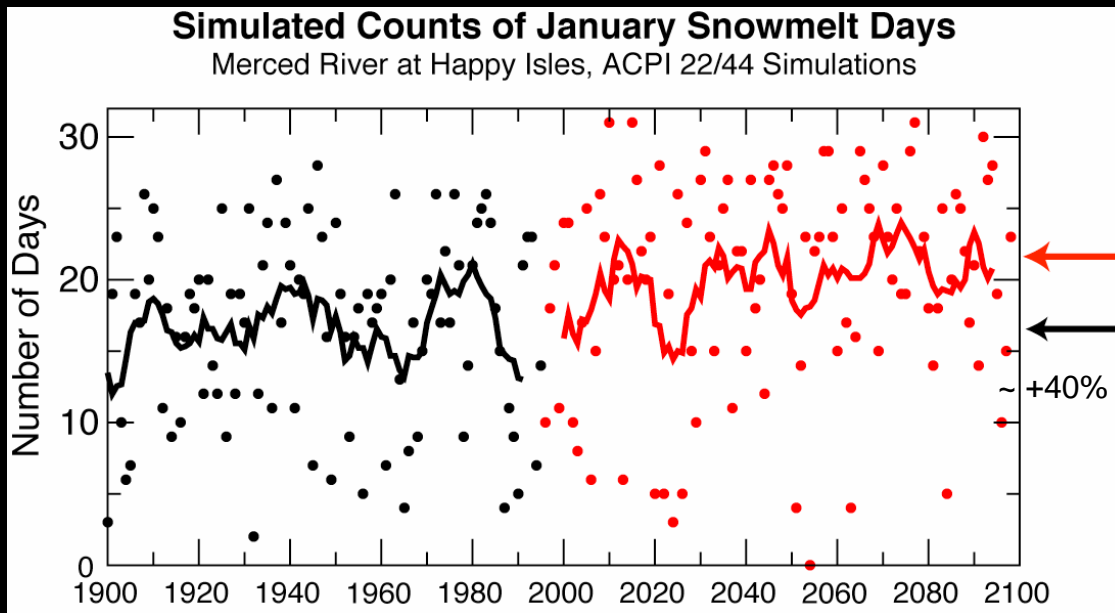
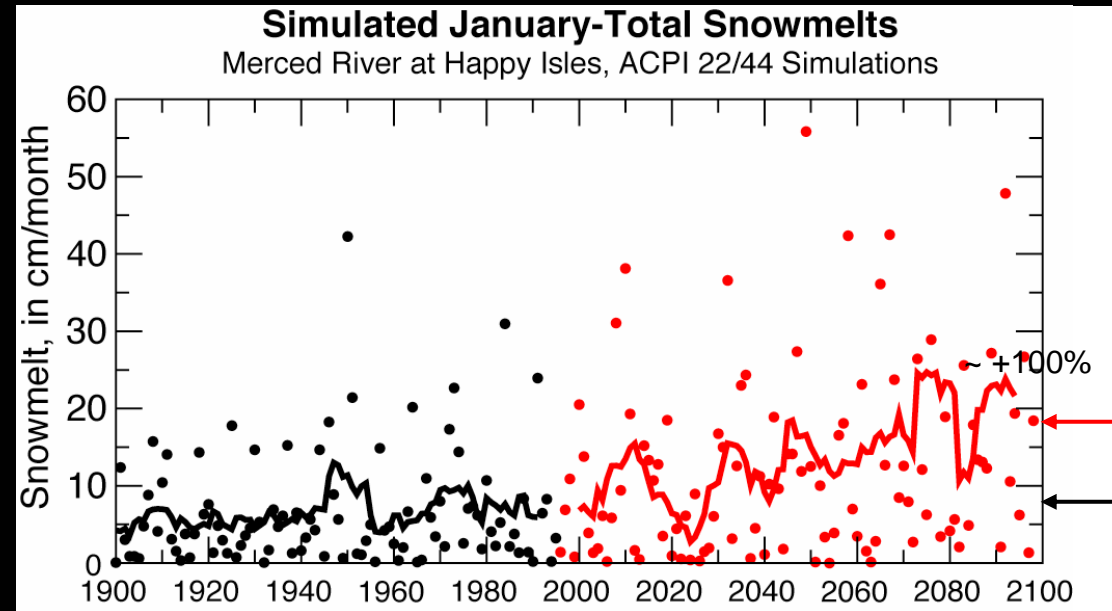


Larger storms?



MORE OR LESS FLOODING?

In a detailed model of Merced R in Yosemite, beneath remaining snowpacks, warming brings a general winter "drizzle" that keeps snows & soils wetter.

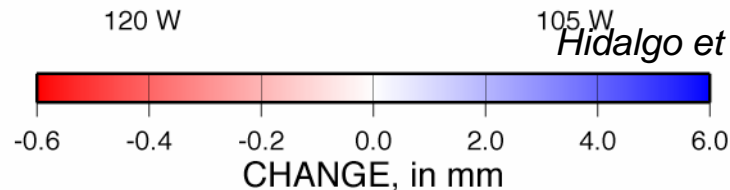
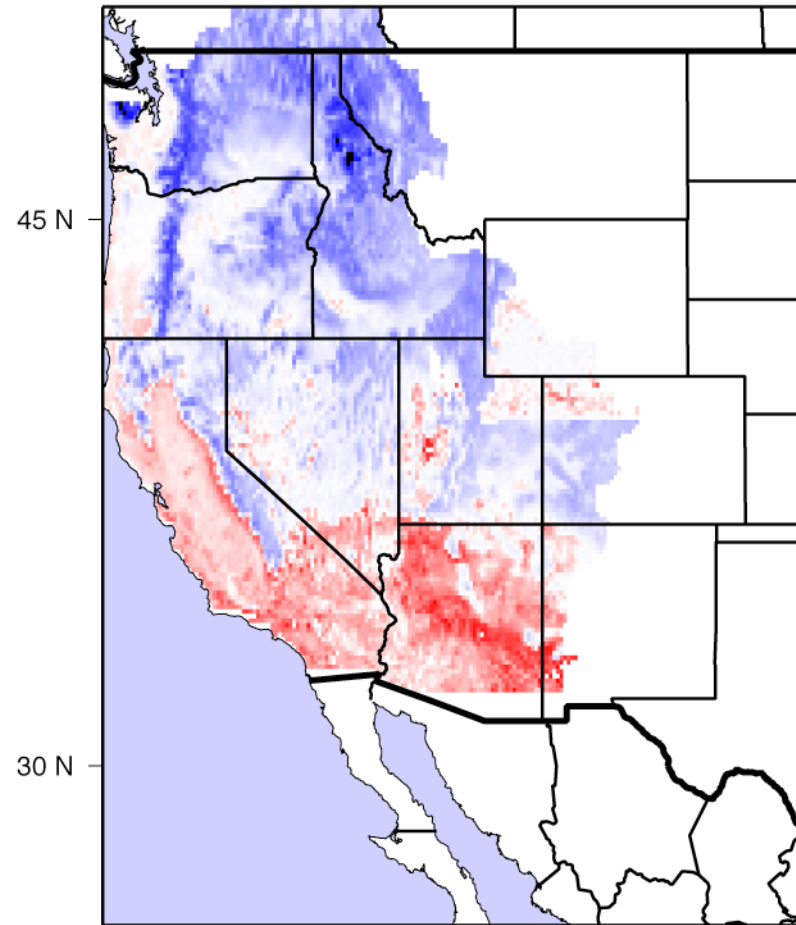


Dettinger et al 2004, Clim. Change

With all this additional winter melting going on, the soils are more, and more frequently, wet during the flood seasons...across the Sierra and central and northern West.

Notice that reds are order of magnitude smaller than blues in this color bar.

CHANGE IN DECEMBER-JANUARY AVERAGED UPPERMOST SOIL MOISTURE under +2°C WARMING

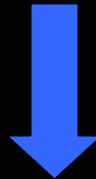


Hidalgo et al, in prep

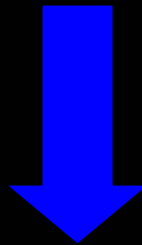
Rain rather than snow! --> Larger contributing areas



Wet snows and soils! --> Flood-friendly antecedents



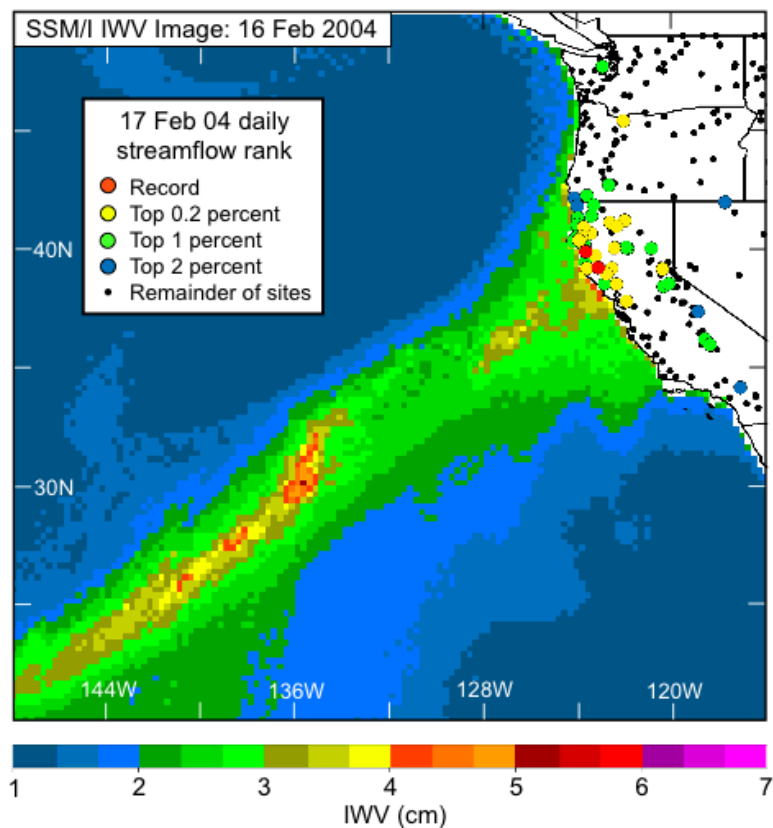
Larger or smaller storms?



MORE OR LESS FLOODING?

THE storms to worry about...

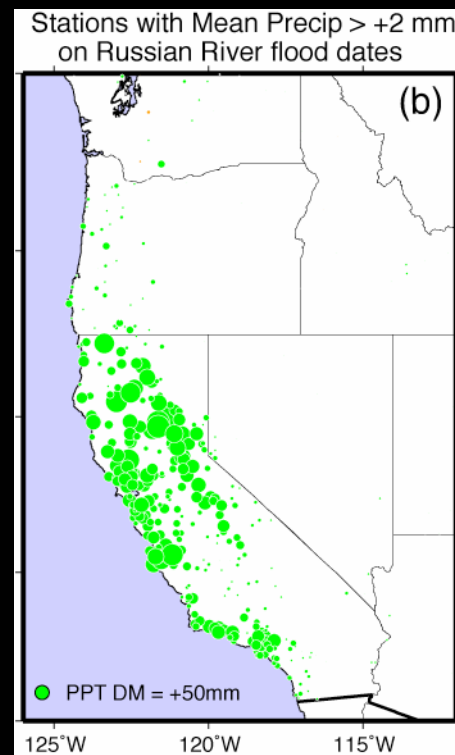
Atmospheric Rivers!



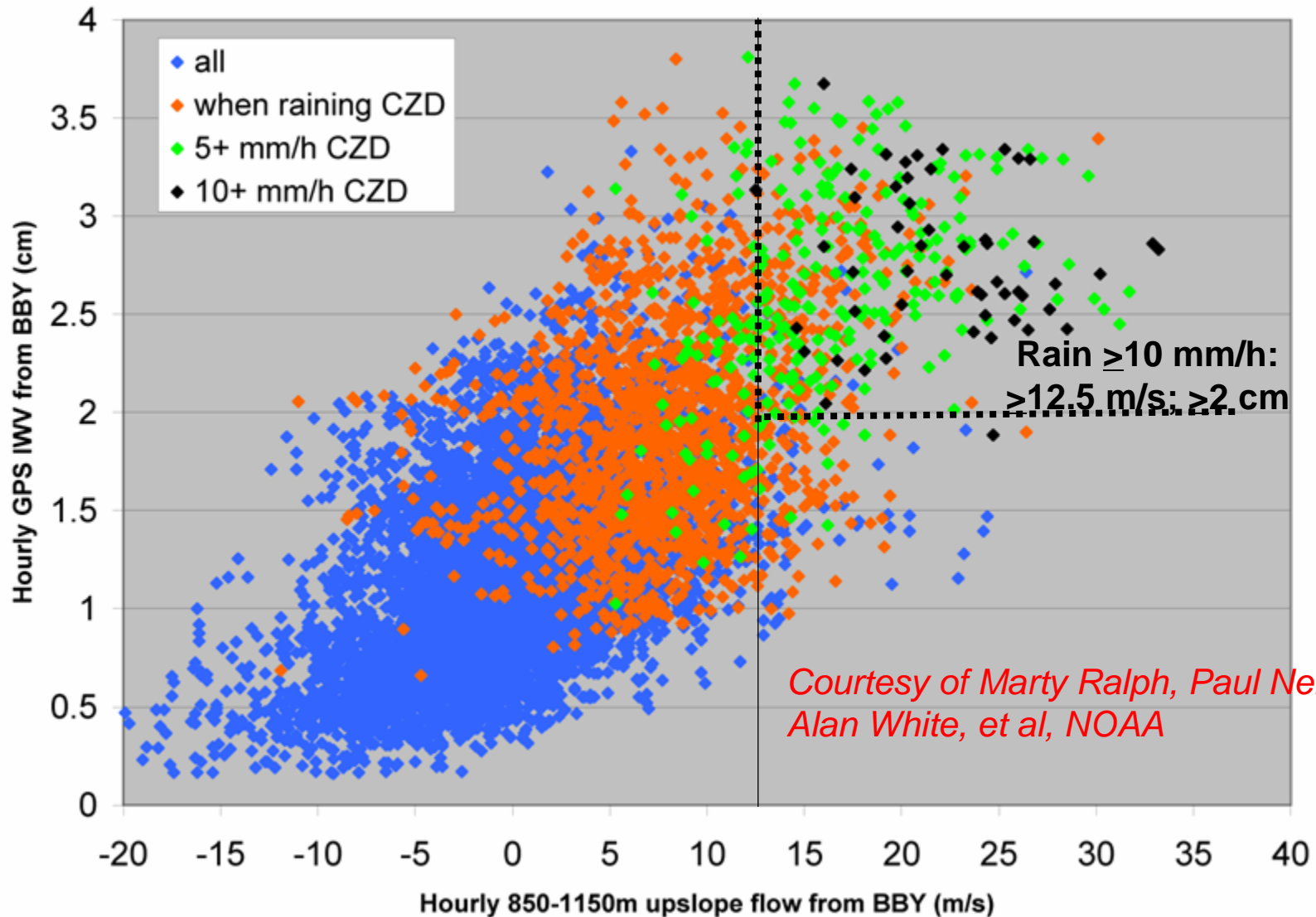
*Ralph et al, GRL, 2006;
Neiman et al, in press;
Dettinger 2004*

- All 7 major floods of Russian River since 1997 have been **atmospheric rivers**
- The 9 largest winter floods of Carson River since 1950 have been atmospheric rivers (i.e., **pineapple expresses**)

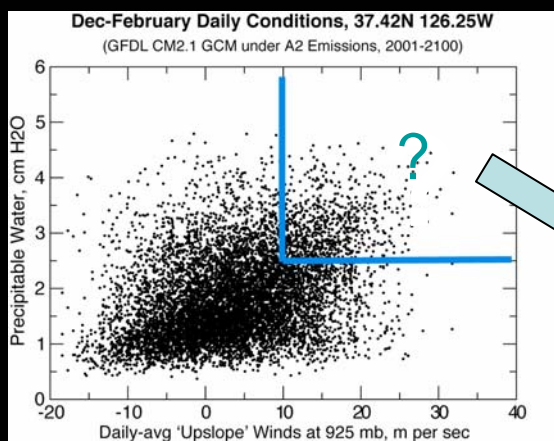
*Corresponding
precip patterns
tend to be
restricted mostly
to Pacific coast
states*



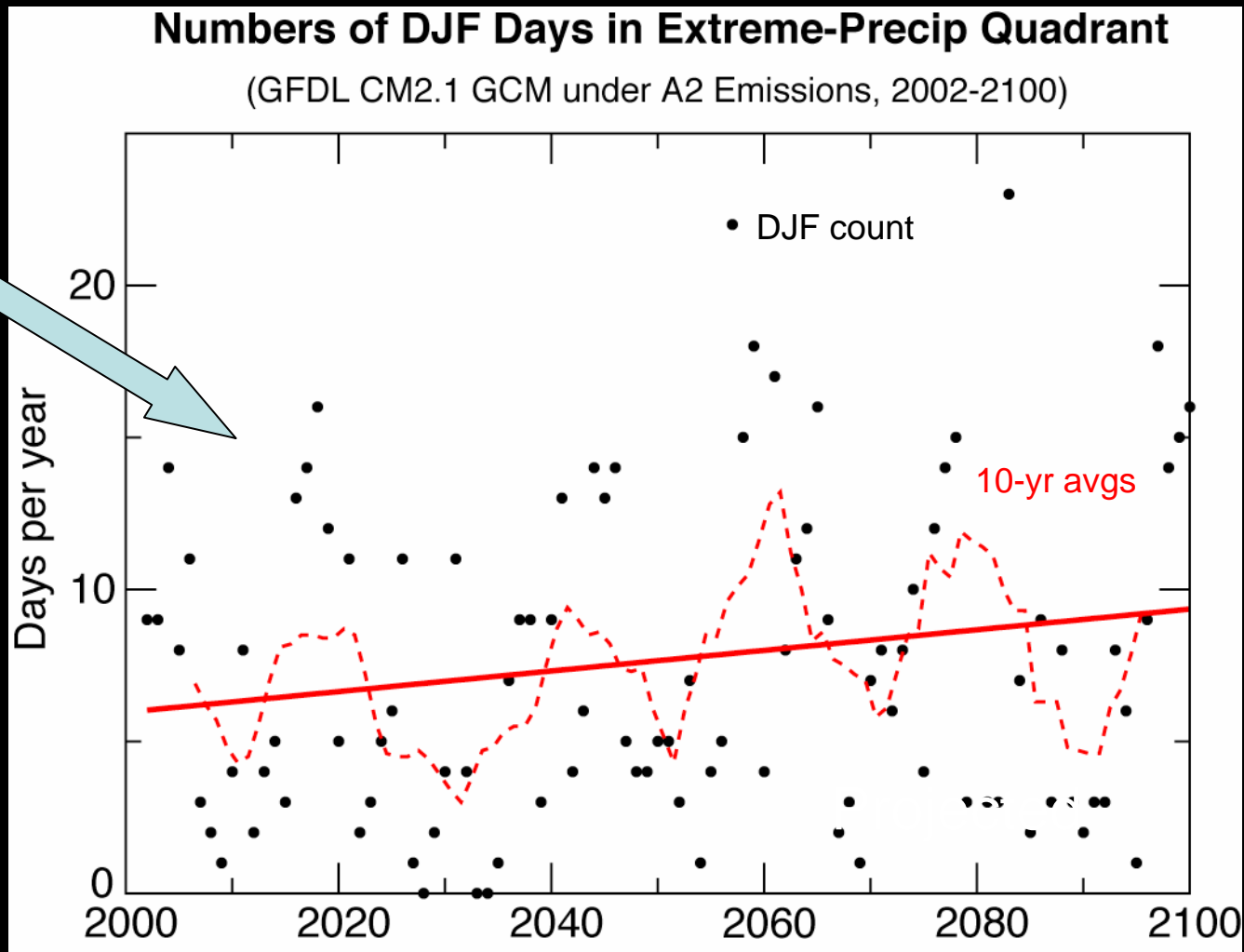
Rainfall Intensity in such storms is predicted by
supply of water --> winds and vapor



How often are historical extreme-precip conditions realized per winter as the climate-change projection progresses?



Projections



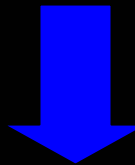
Rain rather than snow! --> Larger contributing areas
(rain on snow?)



Wet snows and soils! --> Flood-friendly antecedents



More large storms!
(larger storms?)



MORE FLOOD RISK!

BETTER FLOOD MANAGEMENT through 21st Century Monitoring!



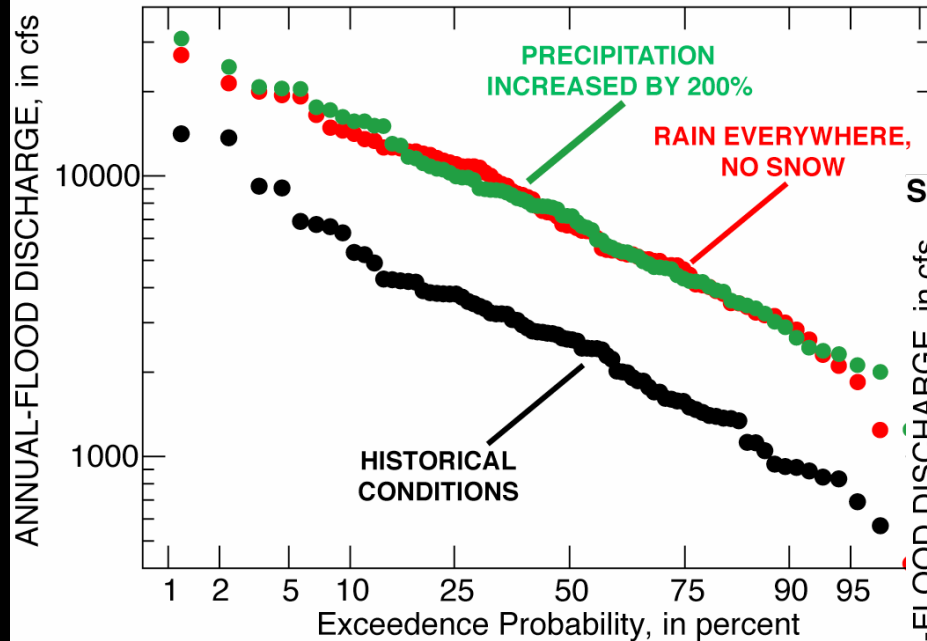
- Monitoring/predicting snowlines storm-by-storm
- Monitoring/predicting soil moisture storm-by-storm
 - Monitoring/predicting storms storm-by-storm

See Marty Ralph's talk later in this session

Does rain-on-snow change the story substantially?

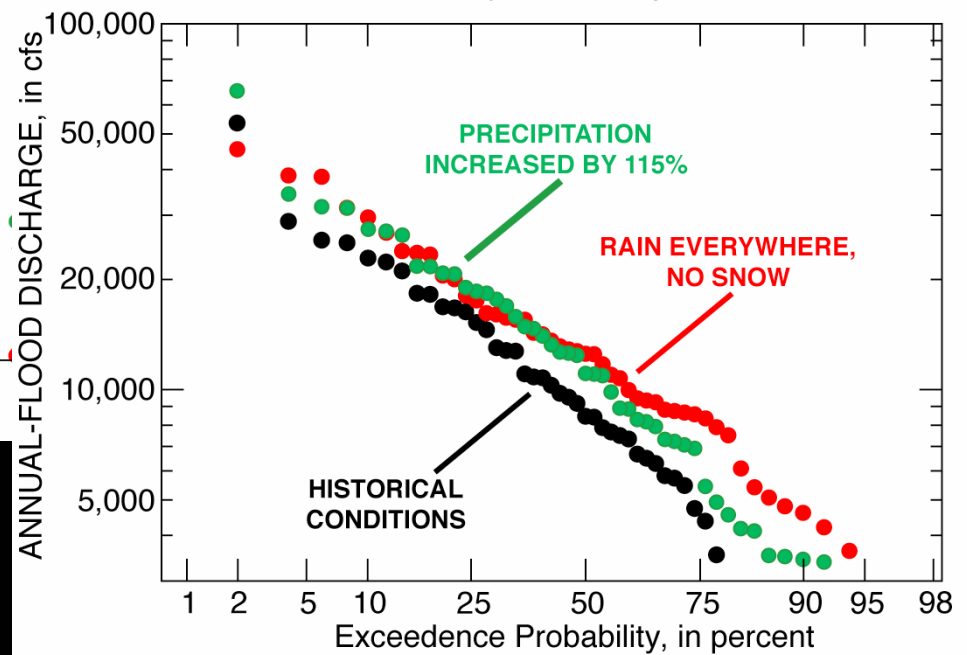
Making ALL precipitation = rain in PRMS simulation models of **Merced River & North Fork American**

SIMULATED MERCED RIVER (Happy Isles) FLOOD STATISTICS



Flood frequencies and magnitudes increase despite having NO snow to rain on.

SIMULATED AMERICAN RIVER (North Fork) FLOOD STATISTICS



(Model described by Dettinger et al, 2004, Climatic Change)

REFERENCES

- Cayan, D.R., Kammerdiener, S., Dettinger, M.D., Caprio, J.M., and Peterson, D.H., 2001, Changes in the onset of spring in the western United States: Bulletin, American Meteorological Society, 82, 399-415.
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- Dettinger, M.D., Cayan, D.R., Meyer, M.K., and Jeton, A.E., 2004, Simulated hydrologic responses to climate variations and change in the Merced, Carson, and American River basins, Sierra Nevada, California, 1900-2099: Climatic Change, 62, 283-317.
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- Mote, P.W., 2003, Trends in snow water equivalent in the Pacific Northwest and their climatic causes. Geophysical Research Letters, 30, DOI 10.1029/2003GL0172588.
- Ralph, F.M., Neiman, P.J., Wick, G., Gutman, S., Dettinger, M., Cayan, D., and White, A.B., 2006, Flooding on California's Russian River—Role of atmospheric rivers: Geophysical Research Letters, 33 (L13801), 5 p, doi:10.1029/2006GL026689.
- Stewart, I., Cayan, D., and Dettinger, M., 2005, Changes towards earlier streamflow timing across western North America: Journal of Climate, 18, 1136-1155.